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Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India—A case study

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ABSTRACT

Coastal zone is exposed to various natural forces including cyclones and tsunamis, which are constantly affecting the shorelines, beaches and headlands, causing storm surges, erosion/accretion, landslides, and coastal flooding. Magnitude and risk of disasters are directly proportional to the sensitivity and inversely proportional to degree of resilience of exposed community. To mitigate the ill effects of hazards, a thorough understanding of the vulnerability causing factors and coping capabilities is required for which vulnerability analysis is essential. A study was undertaken in the most vulnerable coastal zone in Cuddalore District of Tamil Nadu, with a goal to draw a comprehensive vulnerability framework combining Geo-Physical–Natural factors with Socio-Economic-Institutional factors responsible for causing vulnerability at habitation levels and to construct composite vulnerability index (CVI) and dimensional indices. Analysis on changes along the shoreline using the information extracted from the satellite imageries between the years 1972 and 2011 indicated that the average net rate of shoreline change was $+0.15$ m year^{-1}. Of the total length of 42 km studied for shoreline changes, about 40.5% of the coastline is accreting, 15.72% is medium to highly eroded and 18.23% is classified under low erosion zone. The flood hazard mapping study undertaken for a stretch of $\sim$14 km along the Cuddalore coastline for 1-in-100-year extreme flood level, including local mean sea level and global sea-level rise, indicated maximum inundation level to be 3.62 m form MSL for the Cuddalore coastal region. The composite hazard line drawn on the GIS map shows that in the study area seventeen habitations (coastal settlements) are vulnerable to storm surge coastal flooding generated by one in 100 year return period storm surge (3.62 m height). CVI of 17 habitations in study area was developed on a scale of 'one' to 'five' by considering nine broad dimensions of vulnerability viz., geographic, demographic, institutional, natural, social, safety infrastructure, physical, livelihood and economic, each expressed by five indicators, using a total of seventy five variables of vulnerability, with weightage of 22.20%, 13.19%, 13.34%, 13.35%, 9.20%, 6.24%,5.89%, 9.83% and 6.77% respectively, arrived through Analytic Hierarchy Process (AHP). The results indicated that two habitations viz. Samiyarpettai (3.18) and C. Pudupettai (3.10) have CVI in acutely vulnerable (level 3-CVI between 3 and 4) category and rest of the 15 habitations are in the highly vulnerable (level 2-CVI between 2 and 3) category. Dimension wise vulnerability indices appear to differ considerably among different habitations. Institutional vulnerability is in a lower range owing to a better prepared coastal community after 2004 Tsunami. CVI construction enables the policy makers to devise a suitable strategy for vulnerability reduction. The habitation vulnerability mapping provides information for prioritisation of the vulnerability dimensions and is a very useful tool for developing effective policy to reduce vulnerability at habitation level.

1. Introduction

Natural phenomena such as cyclones, waves, currents, tides and storms, tsunamis constantly bring-in changes and sometimes disasters in the coastal zones. Coastal disasters are the most destructive phenomena of nature which result in huge loss of lives and assets and have far reaching after effects. It is estimated that about 1.9 million deaths have occurred globally in last 2 centuries due to Tropical cyclones (Nicholls and Leatherman,

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1995). Trend analysis of global reported disasters for a period from 1975 to 2011 indicates that number of reported disasters and people affected have increased more than four times, while, the casualty reported has reduced to one-sixth (EMDAT, 2012). The coastal regions are densely populated due to developmental opportunities such as major and minor ports, fishing harbours, estuaries of ecological importance, monuments of international heritage, tourist locations, pilgrimage centres, etc. Therefore, despite these hazards exposure, more than 250 million people live within 50 km of the coastline to reap the benefits of the coastal ecosystem and their life and livelihood are exposed to the threats of weather hazards.

India is having a long coastline of ~7500 km, and Tamil Nadu state, situated on the south east of peninsular India. It has extensive coastline of ~1000 km in the east and south bordering Bay of Bengal and Indian Ocean and faces maximum threats from tropical cyclones and associated storm surges during the North East monsoon (October–December). From year 1737 onward, there have been 23 major surge events in the Bay of Bengal, accounting for more than 10,000 human lives lost during each event (Murthy et al., 2006). The damage from tropical cyclones is mainly due to rain, strong winds and storm surges.

The magnitude and risk of disasters depend on the vulnerability of exposed population. Understanding and assessing the risk is fundamental to enhancing the resilience of coastal communities (Asian Disaster Preparedness Center (APDC), 2007). The scale of vulnerability changes with individuals and households as it encompasses the response to risk, coping and potential to react and withstand a disaster (Kumpulainen, 2006). To mitigate the ill effects of hazards, a thorough understanding of the vulnerability causing factors is required. Efficacy of policy interventions for disaster management would depend upon proper understanding of the vulnerability of exposed community and its coping capabilities. Vulnerability assessment helps the decision makers to identify, analyse and reduce the causal factors of disasters by taking systematic efforts to reduce exposure to hazards, lessening vulnerability of people by improving their preparedness and resilience to adverse events apart from wiser management of land and environment. Vulnerability analysis, therefore, is the key activity in risk reduction, preparedness and management of the disaster. As the intensity and frequency of hazards and the extent of exposure to mankind are on the increase, building resilient communities and reducing disaster risk exposure are the two core initiatives for effective disaster management which are assessed only through vulnerability analysis.

Many studies have been conducted in India for natural hazard analysis, vulnerability mapping and development of vulnerability index. Rao et al. (2008) constructed CVI for coastal Andhra Pradesh (AP) as low, moderate, high and very high risk categories for eustatic sea-level rise due to global warming by integrating the differentially weighted rank values of coastal geomorphology, coastal slope, shoreline change, mean spring tide range and significant wave height. Patnaik and Narayanan (2009) developed vulnerability index using fourteen indicators under four dimensions viz. demographic, climatic, agricultural and occupational and ranked the various coastal districts of Orissa and AP for cyclones, storms and depressions in socioeconomic context. Kumar et al. (2010) developed CVI for coastal natural hazards of different magnitude for coastal areas of Orissa using eight relative risk variables collected from different sources including remote sensing satellites, in situ measurements and from numerical models. Zones of vulnerability were identified and shown on a map. Mujabar and Chandrasekar (2011) assessed erosion hazard and vulnerability level by developing CVI along southern coastal TN using geological and physical variables drawn from remote sensing and Geographic Information System (GIS). Mahendra et al. (2011) conducted the vulnerability analysis for Cuddalore, Nagapattinam and Pondicherry coast following Hazard Risk-Exposure approach using Remote Sensing and GIS tools. Input parameters used were probability of maximum storm surge height during the return period, future SLR and coastal erosion. Kumar and Kunte (2012) developed CVI for the Chennai coast using eight relative risk variables to identify the area of inundation due to future SLR and land loss due to coastal erosion through modelling techniques using Remote Sensing and GIS tools. The CVI was calculated using the simple vector algebraic technique using ESRI ArcMap software. Mariappan and Devi (2012), studied the linear extent of 10 km coast south of Chennai for shoreline changes and derived the CVI using geomorphology, shoreline change, slope, wave height, tidal range, and bathymetry as the parameters. CVI was calculated as the square root of the product of the ranked variables divided by the total number of variables.

Li and Li (2011) studied the storm surge vulnerability for coastal cities of Guangdong Province using five vulnerability indices viz. social economic index, land use index, eco-environmental index, coastal construction index, and disaster-bearing capability index. Using ArcGIS, the vulnerability zoning map of storm surges in the study region was drawn. Palmer et al. (2011) studied the relative coastal vulnerability and developed the CVI for KwaZulu–Natal coast in South Africa based on remotely sensed data using a set of seven physical, coastal, social, economic and ecological parameters, evaluated and reviewed by specialist consultation as indicators of risk and vulnerability. The CVI scores of the coastal stretches, arrived at by summing up the vulnerability score of each of the seven parameters, were classified into five classes- from very low to very high, based on the relative degree of vulnerability. Reyes and Blanco (2012) assessed vulnerability to climate change for three coastal villages of Philippines, developed Socio-economic vulnerability index (SEVI) based on population, age, gender, employment, source of income and household size and the CVI using significant wave heights of multiple satellite altimetry missions, coastal topography derived from the 25-m Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), bathymetry from WorldView-2 and additional elevation data from terrestrial laser scanning surveys. The SEVI and CVI were evaluated in ArcGIS and were integrated to determine the Total Vulnerability Index, from very low to very high vulnerability.

From the above, it may be seen that in most of the studies conducted earlier, a sectoral approach has been adopted to develop vulnerability index, considering either risk causing or coping capacity limiting factors. It is necessary to adopt a holistic view and consider all the factors which influence the vulnerability. Further, vulnerability analysis had been done and indices were developed at state, districts and village level but not at the habitation level, the smallest cohesive unit of the society. The averaging effect due to use of macro level data masks the vulnerability variations which exist at the habitation level. As different people subjected to same degree of exposure to a hazard have different vulnerability due to difference in sensitivities and coping capabilities, habitation level vulnerability analysis would provide a precise account and help policy makers to fix the priorities and to make suitable interventions for vulnerability reduction.

The vulnerability index, to be representative, must capture all those variables which substantially express various dimensions and components of vulnerability without major omissions and repetitions. Most of the studies conducted for the vulnerability analysis have used commonly available information as input data. While it helps in getting a general picture of the vulnerability scenario, it may not help the decision makers to prioritise the hard and soft options for disaster risk reduction and resilience building of the particular habitation. Another common deficiency observed in most of the vulnerability analyses is the lack of adequate interaction and involvement of the exposed population in the entire process. As quantitative data may not capture some of the qualitative traits of vulnerability, involvement of target community in the analysis becomes a very important aspect of vulnerability analysis. In the present study, census method has been followed to capture the household vulnerability data and participatory tools such as Participatory Rural Appraisal (PRA) and Focus Group Discussion (FGD) were used to assess the perceptions and understand dynamics of the target community. Vulnerability as a concept must be understood correctly, as people being vulnerable to natural hazards of various types and having various social characteristics that make them likely to be harmed by a particular hazard to a greater or lesser extent (Cannon, 2006, 2008).The current study was undertaken with a goal to draw a comprehensive habitation vulnerability framework combining geo-physical–natural factors with socio-economic-institutional factors. This would aid in simultaneously capturing the natural hazard risk exposure with coping capacity of the community at habitation level.

2. Study area

Cuddalore has been chosen as the study area as it is one of the most vulnerable districts in Tamil Nadu state, and experiences many natural hazards including recurrent cyclonic events resulting in significant loss of life and property. Cuddalore district is located between 11°11' to 12° 35' North latitude and 78°38' to 80° East Longitude and is predominately an agricultural district (Fig. 1). Average elevation of the district is 1 m (3 ft) above Mean Sea Level. It has a coastline of ~57 km with one fishing harbour and five fish landing centres.

Normally during the northeast monsoon, cyclonic storms are formed in the Bay of Bengal. In the past century 60 cyclonic/severe cyclonic surges crossed Cuddalore coast (IMD eAtlas, 2011) and in the past 4 decades, on five occasions (in years 1978, 1991, 1993, 2000 and 2011), considerable damage has been created to Cuddalore district due to cyclonic storms. Large parts of the Cuddalore coast are low lying and with a gentle slope, resulting in large inundation, which increases the vulnerability of the region (Murthy et al., 2006). The stretch between Cuddalore to Nagapattinam is classified as Low Elevation Coastal Zone (LECZ), region below 10 m elevation near the coastline and delineated to designate the population affected from Sea Level Rise (SLR). Cuddalore was one of the worst affected districts of Tamil Nadu in December 2004 Indian Ocean tsunami in which 610 persons reportedly died in the district apart from 38 persons went missing.

The major geomorphic features of the coastal tract in Cuddalore are comprising of upland plain, flood plain, deltaic plain, coastal plains, sub aerial delta, strand plain, estuarine, strandlines, raised beaches, sand dunes, mangroves swamp and tidal flats. As per Census of 2011, population density (persons km^{-2}) of the district is 702 compared to 555 for Tamil Nadu and 382 for India while the literacy rate of the district is 79.04% compared to state average literacy of 80.33%,. Cuddalore is a socially backward district with a majority of the population belongs to either backward/most backward class or the schedule caste. Agriculture and fishing are the two main sources of livelihood in the district.. Analysis of cultivable land holding indicates skewed cultivable land ownership pattern; 92.83% small farmers (owning land up to 2 ha) own 63% of the cultivable land while, balance 7.61% farmers (owning land more than 2 ha) own 36.93% of the cultivable area of the district. These demographic and socio-economic traits, being adverse, increase the vulnerability of the district 45 marine fishermen villages are located in the district with total marine fishermen population of 47,000. The methodology proposed in the study, being comprehensive as well as flexible, may be replicated in vulnerability assessment of other coastal habitations in India.

3. Materials and methods

Key factors that are used for the vulnerability analysis are physical exposure to coastal flooding due to storm surges and ability of the coastal communities to face the hazard. In the current study, the above problem is addressed under three major headings, viz., (1) coastal flood hazard mapping; (2) socio-economic resilience analysis; and (3) vulnerability analysis. Flood hazard mapping is done to estimate the risk associated with 1 in 100 years return period storm surge which helps in identification of the habitations located near to sea coast that are vulnerable to storm surges flooding. The socio-economic resilience study is then carried out to assess and analyse the preparedness, resources inventory and the coping capabilities of coastal communities exposed to the identified hazard. Once the community risk exposure and capabilities are known, the vulnerability analysis framework could be developed and the degree of vulnerability could be quantified in term of composite index and major dimensional indices of vulnerability.

3.1. Coastline change mapping

The coastal change mapping is described under: (1) erosion mapping; (2) flood line mapping; and (3) composite hazard line delineation.

3.1.1. Erosion mapping

Shoreline change in general, is the movement of a specific shoreline. In the present study, remote sensing technology was coupled with limited real time kinematic Differential Global Positioning System (DGPS) surveys on the GIS platform for developing historical shoreline information. From the Survey of India (SOI) toposheet, the base map of coastline was prepared through on-screen digitisation. In order to identify the shoreline oscillations, tide data were collected from the SOI tide gauge station for the

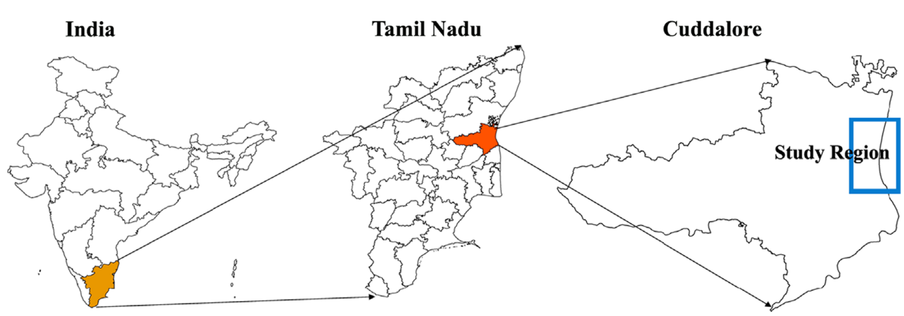

Fig. 1. Map of the study area in the Cuddalore District, Tamil Nadu.

year 1969. For the satellite data, the satellite pass of the nearest station was procured. The toposheet of SOI (1969) and the satellite imageries from LANDSAT-I (27.1.1977), LANDSAT TM (29.1.1991; 11.11.1999; 7.2.2006), IRS LISS III 8.2.2001), EO-1, advance land imager (16.3.2005; 14.2.2009) and CARTOSAT-II (3.6.2011) considered for the analysis are presented in Fig. 2.

The tidal measurement during the time of satellite pass was used to delineate the accurate shoreline during the time of tidal maxima (high tide- the maximum amount of water inundate the landmass). The coordination between a tide gauge reading and satellite imagery was used to ensure the instantaneous shoreline representation corresponding to the desired tide level (Parker, 2003). These variations have been generalised in the current study by considering the data for calm sea conditions, re-sampling techniques through established reference points (benchmarks) for all considered satellite images and also by consideration of shoreline width up to the variable tide affected width of the beach. The latter allows exclusion of tidal effects in shoreline mapping.

3.1.2. Flood hazard mapping

Hazard mapping defines the potential for harm using event return intervals (Pethick, 2009). The return interval for each flood event was computed from the past events. Prediction into the future was made through extrapolation, using statistical distributions (i.e., the 100 years flood height) from the data collected over past 20 years from nearest Chennai Port tide gauge. To determine which areas are at risk of flooding, coastal topographic survey was undertaken along the Cuddalore coast using a Total Station (LeicaTc405), with reference to the SOI benchmark located at the Cuddalore Port. About 5500 control points were obtained from the Low Tide Line (LTL) to the 5 m topographic contour elevation,

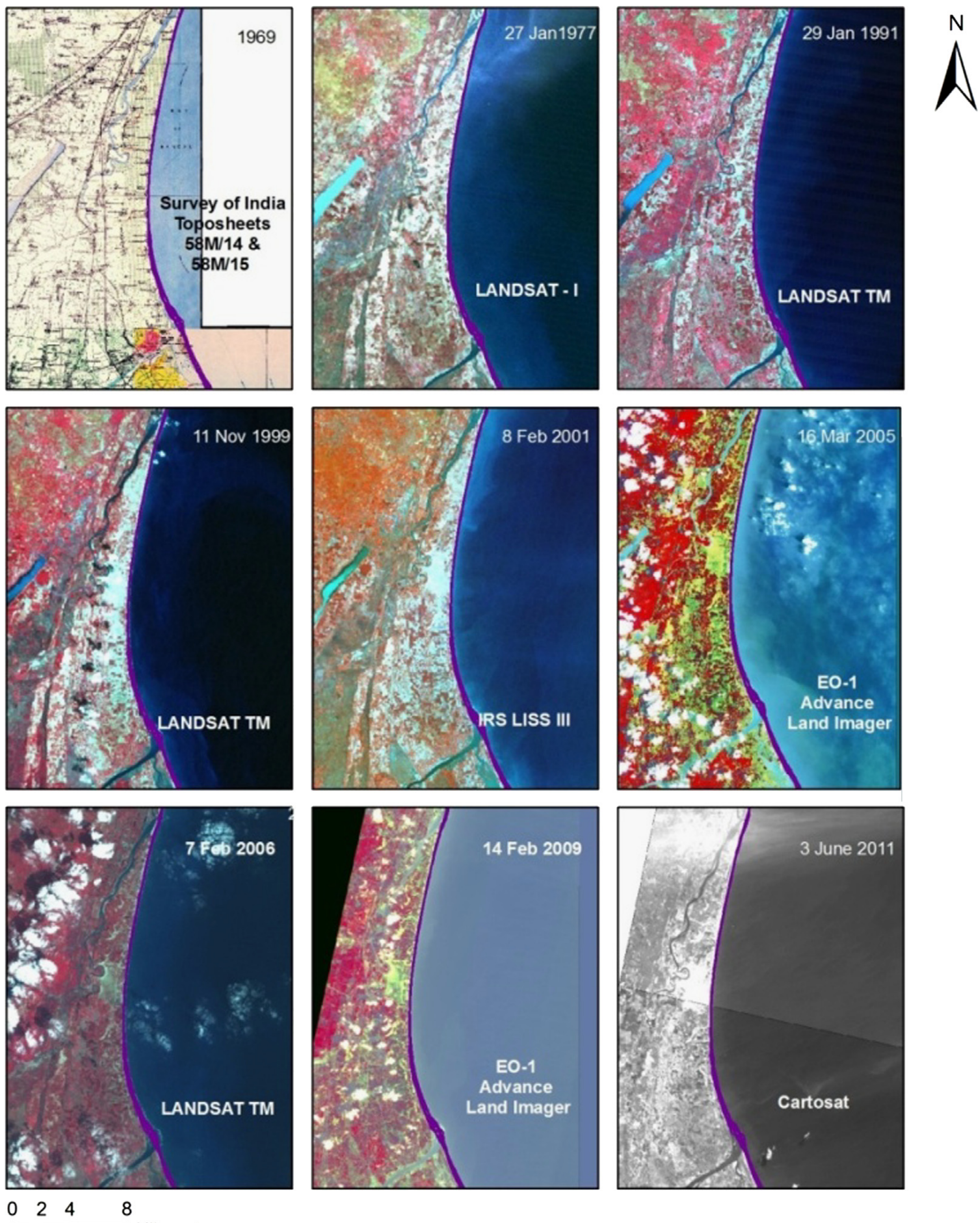

Fig. 2. SOI toposheet-1969 and Satellite Imageries (1972–2011).

that is, approximately 2 km from the High Tide Line (HTL). The topographic survey helped to demarcate the extent of landward movement of extreme water levels. The control points obtained through Total station/DGPS survey were imported through ARCGIS software for creating the digital elevation model of the area of study along Cuddalore coast line.

3.1.3. Composite hazard line delineation

A coastal "*Hazard Line*" is proposed in order to integrate the management of coastal hazards— to cover land, which is at risk from coastal erosion (erosion line) and coastal flooding (flood line) within the next 100 years. On an accreting shoreline, the flood line becomes the composite hazard line while on an eroding shoreline the land effect of erosion also is to be taken in to account. Methodology to demarcate composite hazard line is given in Fig. 3. The primary purpose of the hazard line is to identify zones along the coastline that reflects a potential hazard and risk to people and their property. The composite hazard line represents a margin of safety.

3.2. Socio-economic resilience analysis

For conducting socio economic resilience study, vast amount of data about the individual households, specific groups and community as a whole is required. Primary data has been collected for seventeen vulnerable habitations from field survey through observations, structured recording of responses of important individuals and groups through PRA and FGD, interviews with important stakeholders, case studies to analyse important events and a detailed questionnaire based survey was conducted for all existing 3193 nos. of households in the study area. The coordinates and elevation of individual households were recorded using handheld GPS instruments. Census method has been used to eliminate sampling error. The qualitative as well as quantitative information is collected to capture the values of variables identified to assess vulnerability such as community's sensitivity and ability to face hazards, availability of traditional skills to predict and effectively respond to hazards, early warning mechanism, social cohesion, team spirit and administrative preparedness and response mechanism for evacuation, rescue and relief etc. Socio-economic

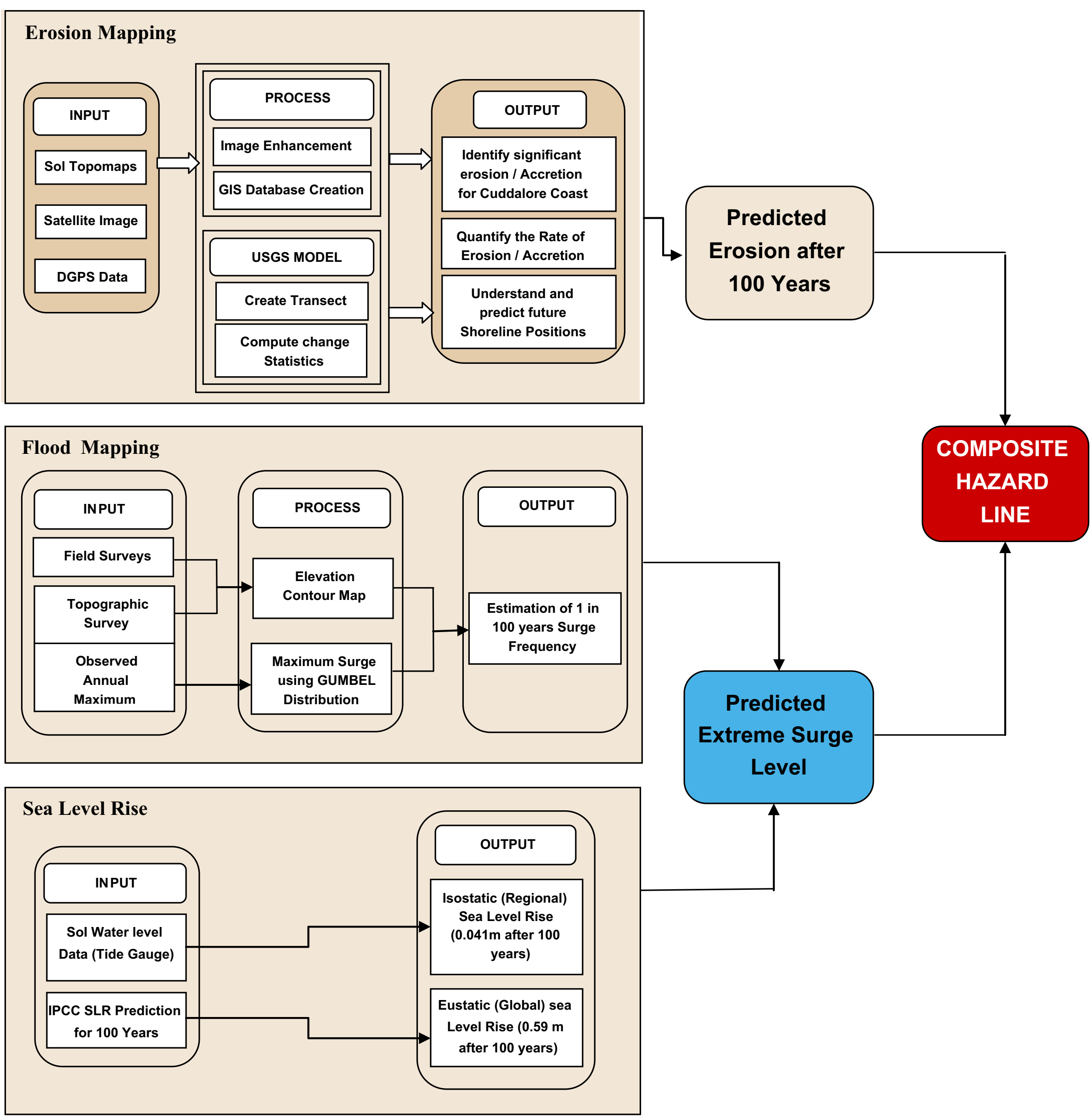

Fig. 3. Methodology for delineation of a composite hazard line.

capital which is a measure of unity, intermixing and community responsiveness on one hand and livelihood security and economic resilience on the other is an indicator of coping capacity of the community. The coping capacity of a habitation increases when a majority of its households have assured source of employment. Secondary data such as average annual precipitation, availability of disaster management plans, zoning, evacuation and mitigation plans, road infrastructure and public transport, NGO network etc. has been collected from various administrative and development agencies of the state and central government, national and international organisations, community organisations and NGOs. Flow chart for collection of field survey, information and data collection is given in Fig. 4.

3.3. Vulnerability analysis framework

To measure vulnerability, indicators that cover both damage potential and coping capacity were used. Absolute values of variables were converted into a common vulnerability rank scale of 'one to five' and relative importance or weightage of individual vulnerability variable was arrived at by applying AHP, a multi

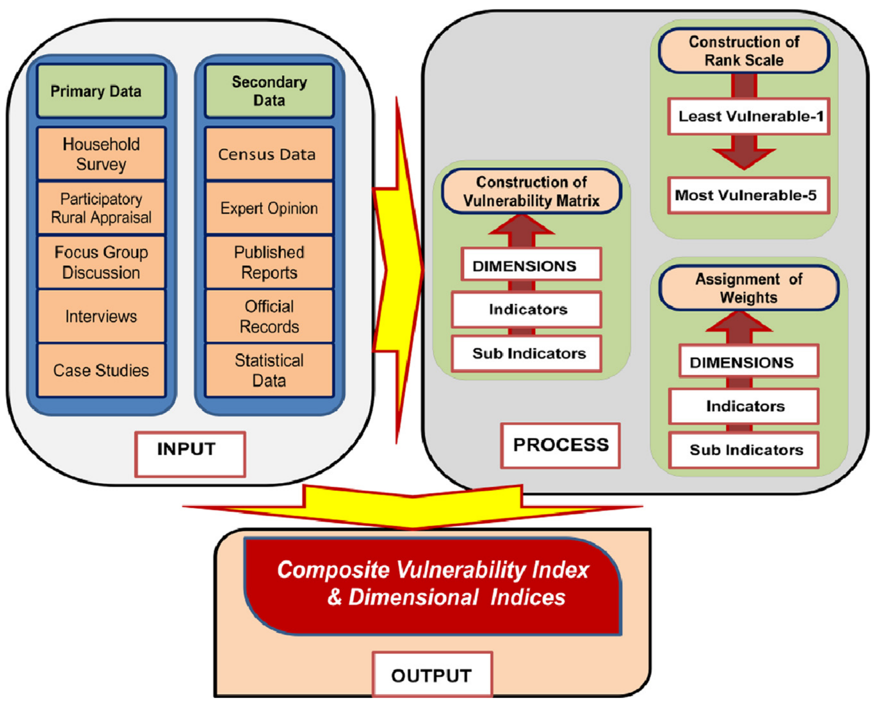

Fig. 4. Methodology for vulnerability assessment.

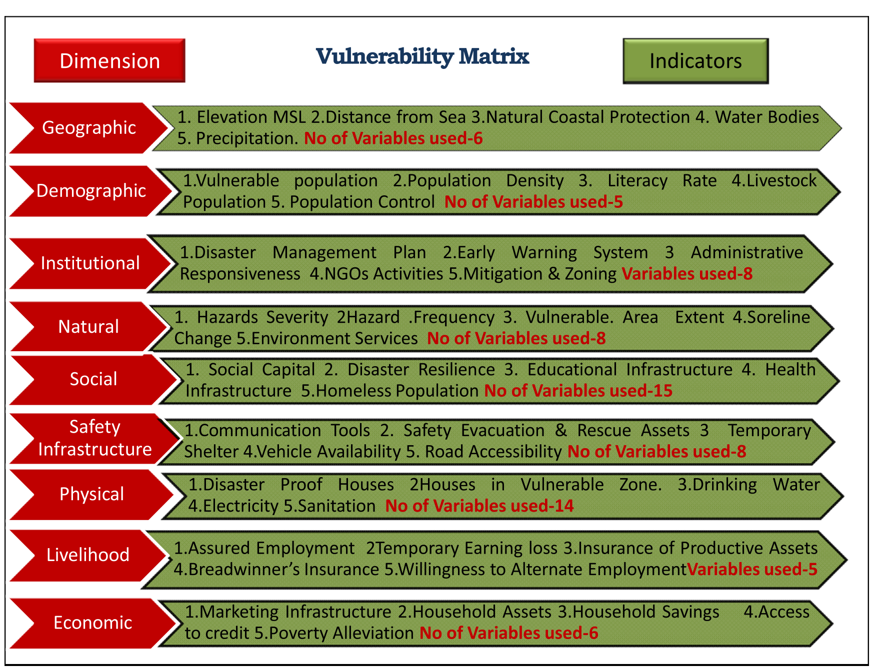

Fig. 5. Details of dimensions, indicators and variables chosen for vulnerability analysis.

criteria decision making technique to arrive at the relative weights of unrelated qualitative traits through unbiased expert judgment, developed by Saaty (1980). Weighting and combining the selected dimensions created an integrated CVI and an integrated vulnerability map to depict the levels of vulnerability of the study area was created.

3.3.1. *Vulnerability matrix*

A total of 75 variables/parameters were selected to map the overall vulnerability of the seventeen vulnerable habitations in the study area based on stakeholders' inputs, extensive literature reviews and expert view. These variables were grouped under nine broad dimensions, each expressed by five indicators and the associated sub indicators to develop vulnerability matrix (Fig. 5).

3.3.2. *Construction of CVI*

To bring indicators of various dimensions expressed by associated parameter/variables to a common scale of degree of vulnerability, every indicator as well as variable/parameter has been rated between 1 (good, Least vulnerable, available/existent, fully sufficient) and 5 (poor, extremely vulnerable, non-existent/non-available, insufficient) based on the quantitative/qualitative measures of the parameter/variable. The vulnerability levels followed in the study are: moderate, high, acute and extreme with rank values <2, 2–3, 3–4 and >4 respectively. The Index of vulnerability for each of the dimensions was arrived by taking weighted average of the scale ranking assigned to each of the indicators and parameters/variables. The weights of Sub indicators, Indicators and dimensions were arrived using AHP (Fig. 7). Rank scale construction and relative weightage computation for dimension/indicator/sub-indicator were made using the inputs from stakeholder and the expert judgement during field survey. To develop the CVI of the coastal community, the weighted average of dimensional vulnerability indices was computed (Fig. 4). The Habitation vulnerability index and dimensional indices were calculated using the following equation:

$$\sum_{j=1}^{n} \boldsymbol{X}j*\boldsymbol{W}j/\sum_{j=1}^{n} \boldsymbol{W}j=\boldsymbol{V}hvi$$

where $\boldsymbol{V_{hvi}}$ = total vulnerability of habitation; $\boldsymbol{X_j}$ = rank scale value of Jth variable; $\boldsymbol{W_j}$ = weight of the Jth variable; $\boldsymbol{n}$ = number of variables.

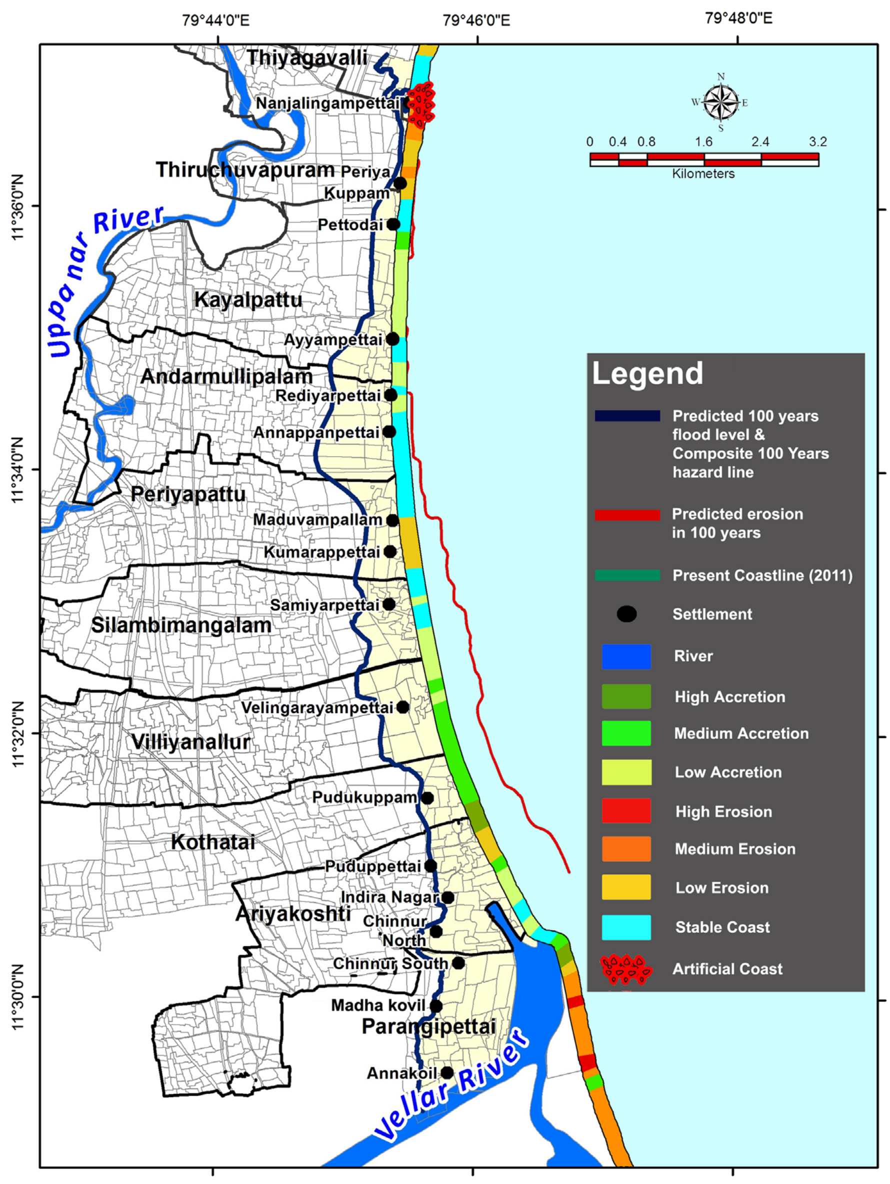

Fig. 6. Lines depicting the predicted erosion/flood level in 100 years, the Composite 100-year hazard line and vulnerable coastal habitations of the Cuddalore coast.

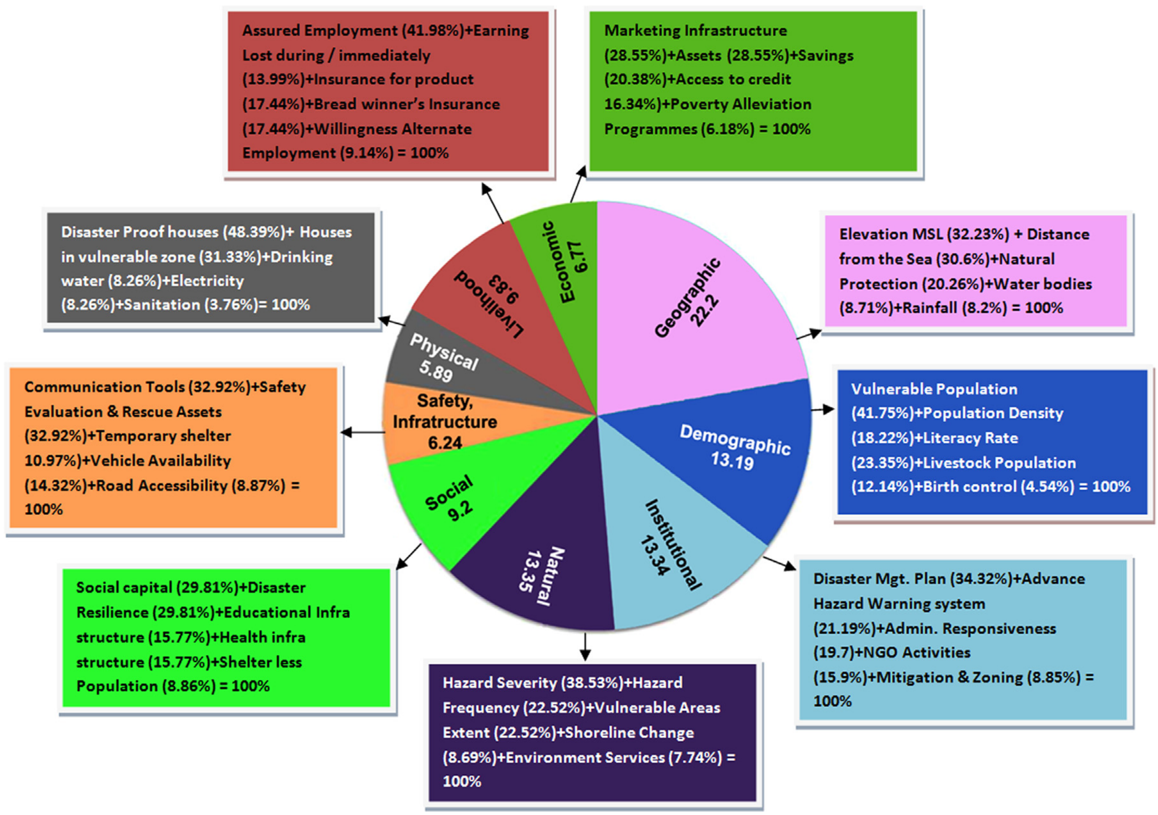

Fig. 7. Habitation vulnerability-weightage of indicators and dimensions in percentage.

4. Results and discussion

4.1. Coastline change mapping

In the present study, the changes in shoreline of Cuddalore due to the processes of accretion and erosion were estimated using the information extracted from the satellite imageries between the years 1972 and 2011.

4.1.1. Erosion mapping

Shoreline change trend reversals indicate that the shoreline of Cuddalore has undergone both erosion and accretion on a long-term basis (Fig. 6). Rates of shoreline change are more uniform along the central part of the study site between Vellar and the Uppanar rivers (Fig. 6). The average net rate of shoreline change was $+0.15$ m year^{-1}. Overall, the coast of Cuddalore District can be classified as an “accreting coast”. Of the total length of 42 km studied, about 40.5% of the coastline was accreting, 25.5% of the shoreline was stable showing no marked change and 34% of the coastline was eroding.

4.1.2. Flood hazard mapping

The flood hazard mapping study was undertaken for a stretch of ~14 km along the Cuddalore, in response to a recent increase in the level of destruction caused by (1) Tsunami (December 2004); (2) Cyclone Nisha in November 2008 and (3) Cyclone Thane in December 2011. The results of 1 in 100 year return level interval, maximum water level experimented through four different methods viz., California, Hazen, Weibul and Gumbel's methods (Saxena et al., 2013) indicate that Gumbel's distribution shows the highest correlations ($r=0.9884$). The water-level data was then ranked in ascending order, and the return intervals were calculated using Gumbel's Distribution. The results indicate that the 1-in-100-year extreme flood level including local MSL and global sea-level rise was calculated to be 3.619 (~3.62) m MSL for the Cuddalore coastal region.

4.1.3. Delineation of composite hazard line

The predicted 100 years flood level and the predicted erosion in 100 years were transferred to the map of the study area in order to demarcate a “Composite Hazard Line”, which was represented by the more landward of the two lines. It was observed that for this coastal stretch along the Cuddalore District, the flood line was always the most landward, and thus, the predicted 100 years flood line becomes the composite hazard line (Fig. 6). Assessment of multi-hazard vulnerability along the Cuddalore coast indicated that river systems act as the flooding corridors that carry larger and longer inter land inundation. Settlement of Anna Koil (Port Novo town panchayat) located at the mouth of the Vellar River is subject to maximum inundation. The composite hazard line drawn on the GIS map shows that in the study area seventeen habitations (Coastal Settlements) are vulnerable to storm surge coastal flooding generated by the 3.62 m height one in 100 year return period storm surge (Fig. 6).

4.2. Socio-economic resilience analysis

Coastal communities are subjected to unprecedented changes due to constantly increasing population growth (Adger et al., 2005), developmental activities and climate change. Hence, these communities become highly vulnerable to natural hazards. The resilience of socio-economic–ecological systems may be expressed as a combination of the magnitude of risk that the system can absorb and remain unaffected within a given state without changing permanently (Folke et al., 2002).

4.2.1. Community perception of risk and traditional coping capacity

Cuddalore coast is exposed to multiple hazards such as cyclones, tsunamis, sea storms, storm surges, coastal flooding, shoreline variations and climate variability/change. Coastal community in the study area feel that cyclonic storm is the most frequent hazard they are exposed to, followed by heavy rains, flooding and wind storms, which causes loss of livelihood and productive assets viz. fishing boats and nets. The community perceived that the frequency and severity of hazards is increasing and they unanimously recorded that tsunami of 2004 was the most devastating of hazards. The inhabitants felt that the frequency as well as intensity of tsunami in future would increase and tsunami of 2004 has changed the pattern of sea waves, wind and currents which adversely affected their livelihood by reducing the fish availability in the sea. People also felt that sea level rise is one of the real threats which would inundate coastal area threatening their livelihood sooner than later. They also stressed the need for reliable early warning system and better disaster preparedness for minimising the impacts of natural hazards.

The coastal community over a period of time has acquired traditional wisdom to predict the onset of hazard with fair degree of confidence and also set of actions as emergency response system to reduce the losses as a result of a hazard on the basis of experience accumulated over many decades coupled with minute observations of natural phenomena such as changes in the pattern of sunrise and sunset, patent and direction of sea current, pattern and height of sea waves, unusual behaviour of local birds and sudden movement of crabs away from sea, pattern of wind flow, tides, cloud's colour & movement etc. Village elders play an active role to guide others in deciding when and where to move in the event of alert for any potential hazard is made.

4.2.2. Socio economic capital

In the study area, the degree of social intermixing among the members varies from moderate to poor and the ability of members to work as a group from limited to moderate extent. Further, number of households willing to take up community responsibility varies from 20% of the households in Madhavapallam habitation to almost all households in Annappanpettai, Velingaranpettai, Indira Nagar and Kumarapettai. Villagers hold informal meetings to discuss about the risk exposure and to identify the ways to reduce it as in their perception vulnerability is a dynamic phenomenon which changes temporally. The general perception of the community is that administrative authorities should interact with the community before drawing and formulating the community development policies, plans and programs and their implementation in general and disaster mitigation planning in particular, and monitoring needs to be done in a participatory and transparent manner. Livelihood of most of the household being marine fishing based, gets affected during coastal hazards. A majority of the households have assured source of employment in all habitations except Annappanpettai and Samiyarpettai.

4.2.3. Institutional mechanism—early warning, evacuation and emergency response

District administration in the study area has developed village level disaster management plans for each of the coastal villages. The early warning is generally received by the community from the local body representatives, government officials- from fisheries and revenue departments, community leaders, media and sometimes over phone from friends and relatives living abroad. Majority of the population is responsive to the early warning and takes steps to move to safer places apart from alerting others also. Availability of trained manpower locally for evacuation and rescue operation and rescue boats varies from limited to sufficient extent. Out of seventeen habitations in study area, capacity of identified buildings as temporary shelters is sufficient in twelve habitations while it is to a limited extent in balance five. The local administration has enough capacity to provide safe drinking water, emergency first aid assistance and food grain and kerosene provisions in the event of a disaster. Mock drills are conducted regularly. There is a general feeling of need for more sensitization and participatory updation of disaster Management plans.

4.3. Analysis of habitation vulnerability

Vulnerability of a community is a reflection of risk exposure and coping capacity of its individual members. Composite vulnerability index of each of the habitation in study area has been developed by considering the weighted rank value of all of the seventy five number of representative variables selected for the vulnerability analysis.

4.3.1. Development of composite index and dimensional indices

The dimensions indicators and their weightage for habitation vulnerability analysis are given in Fig. 7.

Details of vulnerability indices and CVI for all the habitations in the study area are given in Table 1.Composite vulnerability index analysis of 17 habitations in study area shows that two habitations viz. Samiyarpettai (3.18) and C. Pudupettai (3.10) have CVI in acute level (level 3-CVI between 3 and 4) category and rest 15 habitations are in the high level (level 2-CVI between 2 and 3) category. As the CVI values lie between 2.48 and 3.18, there is not much variation in the CVI of habitations. Dimension wise vulnerability indices appear to differ considerably among different habitations. Geographical vulnerability ranges from highest in Pudukuppam (acutely vulnerable) to lowest in Madhakoil (highly vulnerable) while demographic vulnerability varies from highest in Chinnur South (extremely vulnerable) to lowest in Annapanpettai (Moderately Vulnerable). Samiyarpettai is found to be most vulnerable habitation at the time of study in year 2010-11 whereas, sensitization and disaster risk management training given to the community under GOI-UNDP disaster risk management programme a couple of years before tsunami 2004 had significantly reduced the losses suffered by Samiyarpettai as compared to nearest settlement Pudukuppam which had identical size and development level. The study suggests that Institutional vulnerability is in a lower range owing to a better prepared coastal community after 2004 Tsunami.

Natural vulnerability index ranges from highest in Samiyarpettai (extremely vulnerable) to lowest in Reddiyarpettai (Highly Vulnerable) while Social vulnerability index is highest for C. Pudupettai (acutely vulnerable) and least for Periyakuppam (highly vulnerable). Safety infrastructure vulnerability index is highest for C Pudupettai (acutely vulnerable) and least for Pudukuppam (moderately vulnerable), which points the need of improving the safety and communication infrastructure. A lower

Table 1
Composite vulnerability index and dimensional indices.

Habitation ↓	Geographic	Demographic	Institutional	Natural	Social	Infrastructure	Physical	Livelihood	Economic	Composite
Weightage →	*22.2*	*13.19*	*13.34*	*13.35*	*9.20*	*6.24*	*5.89*	*9.83*	*6.77*	*100*
Nanjalingampettai	3.32	3.02	2.85	3.60	2.68	2.33	2.85	1.36	3.18	2.90
PeriyaKuppam	3.06	3.40	2.08	3.39	2.09	2.21	2.08	1.09	2.60	2.59
Pettodai	4.13	2.74	1.96	3.13	2.91	2.14	1.96	1.18	2.65	2.84
Ayyampettai	3.74	2.71	2.95	3.22	2.36	2.22	2.95	1.09	3.28	2.82
Reddiyarpettai	3.72	2.71	2.52	2.84	2.64	2.36	2.52	1.61	2.60	2.77
Annappanpettai	3.03	1.55	2.68	3.38	2.53	2.22	2.68	3.06	2.44	2.70
Madhavapallam	3.81	2.34	1.61	3.17	2.72	1.70	1.61	1.53	2.95	2.66
Kumarapettai	4.01	3.36	1.25	3.58	2.41	1.66	1.25	1.79	3.33	2.87
Samiyarpettai	3.62	3.97	1.21	4.02	2.40	2.24	1.21	2.59	3.38	3.18
Velingarayanpettai	3.82	2.90	2.34	3.80	2.56	2.68	2.34	1.18	1.31	2.77
Pudukuppam	4.47	3.73	1.65	3.55	2.55	1.59	1.65	1.17	2.64	2.91
C. Pudupettai	4.08	3.31	2.14	3.39	3.11	3.02	2.14	1.73	2.25	3.10
Indira Nagar	2.89	2.35	1.12	3.32	2.61	2.88	1.12	1.36	1.86	2.48
Chinnur North	2.64	3.08	1.24	3.34	2.72	2.94	1.24	1.79	2.32	2.58
Chinnur South	3.40	4.50	1.38	3.34	2.63	2.91	1.38	1.52	1.79	2.92
Madhakoil	2.57	3.02	1.36	3.54	2.25	1.75	1.36	2.05	1.86	2.48
Anna Koil	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Extreme
Acute
High
Moderate

range of physical vulnerability index for the habitations, from Ayyampettai (highly vulnerable) to Indira Nagar (moderately vulnerable), suggests that basic community infrastructure of the habitations is reasonably good. Livelihood vulnerability index is highest in Annappanpettai (acutely vulnerable) and lowest in Periyakuppam (moderately vulnerable) while Economic vulnerability index is highest for Samiyarpettai (acutely vulnerable) and least for Velingarayanpettai (moderately vulnerable). Study suggests immediate attention to improve resilience of Samiyarpettai and C Pudupettai has to be taken considering that composite vulnerability index of both of these habitations falling in acutely vulnerable category.

5. Conclusions

It is not the intensity of natural hazards but the degree of vulnerability, i.e., sensitivity and resilience of the exposed population, which decides the magnitude and risk of coastal disasters caused by natural hazards. Construction of vulnerability index has many advantages. An index provides a qualitative rating that helps to prioritise key issues that need to be addressed, index construction enhances the analysis of subjective traits and it is useful in summarizing and communicating the vulnerability assessment results to decision makers and stakeholders. Vulnerability analysis of 17 habitation Pudupettai (3.10) have CVI in acutely vulnerable category and rest of the 15 habitations are in the highly vulnerable category. The CVI construction enables the policy initiations in study area and developing CVI considering geo-physical and socio-economic aspects of vulnerability indicates that two habitations viz. Samiyarpettai (3.18) and decision makers to devise a suitable strategy for vulnerability reduction. The study suggests a constant need to update the disaster preparedness as vulnerability changes temporally. An important finding of the study is that the community, particularly the village elders, have traditional wisdom to predict and foretell about an imminent hazard and may also suggest the way for evacuation. Another significant finding of the study is that a top down approach by the administration to draw up disaster management plan does not fully serve the purpose. The local community need to be involved at every stage from the very beginning in developing a disaster management plan. Appropriate land use planning and proper management of available resources play a critical role in reducing risks.

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